ESTUARINE INFILL AND FORMATION OF DELTAIC PLAINS, SHOALHAVEN RIVER

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Abstract

The Shoalhaven River is an example of a mature, infilled estuary on a wave-dominated coast. The river presently flows between prominent levées towards the coast, periodically exiting at Shoalhaven Heads, but having much of its flow artificially diverted to exit at Crookhaven Heads. The alluvial plains east of Nowra are the result of estuarine infilling behind a sand barrier, represented by Comerong Island, a southern continuation of the Seven Mile Beach beachridge plain. Drilling has revealed marine sands adjacent to this eastern sand barrier, and extensive muds, deposited in a barrier estuary beneath most of the plains. The molluscan composition of these sediments indicates deposition in brackish water conditions, with Notospisula trigonella especially widespread. Estuarine infill occurred progressively around deltaic channels, isolating smaller basins which accreted subsequently. Most of the estuarine sedimentation occurred 5500-3500 radiocarbon years BP. Brackish-water muds grade upwards into fresh-water alluvial muds deposited from fluvial overbank flows, and the transition is indicated from analysis of the diatoms within sediments in an augerhole near Jaspers Brush. Levées overlie these estuarine sediments in places and indicate natural changes in river channel location. There is an extensive potential acid sulphate soil hazard throughout the plains as a result of the occurrence of pyrite-rich estuarine muds up to an elevation close to mean sea level beneath most of the plains.

Introduction

The lower Shoalhaven River is characterised by extensive low-lying alluvial plains which have developed as a result of deltaic-estuarine infill during the last few thousand years. It has long been apparent that these plains are underlain by potential acid sulphate soils which arise from the oxidation of pyrite-rich sediments deposited under brackish water conditions (Norwood, 1975; Willett and Walker, 1982). There has recently been a wider recognition of the distribution of acid sulphate soil conditions and the impacts that acidic, or aluminium-rich waters draining from such plains can have (Sammut et al., 1995; Sammut et al., 1994).

A series of estuarine systems can be recognised along the New South Wales coast, ranging from drowned river valleys, to barrier estuaries, to saline coastal lakes that may be intermittently open to the sea. These estuaries have filled in both with landward
reworking of sand from the shelf and fluvial input of sand and mud from the catchment (Roy, 1984b, Roy, 1994). Each estuary may go through youthful to mature stages as it progressively infills, with those systems with a large catchment, or draining highly weathered and erodible hinterland, likely to infill most rapidly (Jennings and Bird, 1967). The Shoalhaven River is a classic example of a wave-dominated delta (Wright, 1985). The steep continental shelf offshore permits wave energy to propagate almost unattenuated to reach the shoreline (Wright, 1970). Wave energy has reworked sand barriers landwards during the Holocene (the past 10,000 years) as sea level has risen from a low at the last glacial maximum (Roy et al., 1994).

The Shoalhaven is one of the largest rivers draining southern New South Wales and is considered to have almost completely infilled the pre-existing estuarine embayment (Roy, 1984a). The river is highly channelised (the broad estuarine waterbody has become replaced by a confined fluvial channel) and now supplies sediment directly to the coast, in contrast with most estuaries along the southern New South Wales coast which are in less mature stages of infill, and in which bedload sandy sediment is retained within the estuary (Wright, 1970; Roy, 1994).

Detailed studies of the chronology of sand-barrier progradation along Seven Mile Beach have been undertaken, demonstrating a decelerating progradation over the past 6000 years (Thom et al., 1978). Limited drilling on the sand barrier on Comerong Island has revealed a similar age structure (Thom et al., 1981). Infill of the extensive plains west of Comerong Island has been inferred to have occurred in a formerly more extensive barrier estuary or coastal lake.

Geomorphology of the Shoalhaven Estuary (Roy, 1984a, 1994). However, with the exception of radiocarbon dating of estuarine sediments at around 4000 years ago along a transect in mid plains (Willett and Walker, 1982), relatively little is known about the nature and timing of infill of the deltaic-estuarine plains themselves.

This paper describes results from an extensive drilling program to investigate the nature of the sediments beneath the plains. The study has involved an examination of the macrofossils of the sediments, particularly molluscan composition, paleoenvironmental change indicated by diatom assemblages in the upper part of the plains, and a preliminary radiocarbon chronology to establish the pattern of deposition of those sediments which now pose a potential acid-sulphate soil hazard.

Area of Study

The Shoalhaven River is one of the biggest rivers on the southern coast of New South Wales. It drains a catchment of 9260km², much of which is rugged country associated with the Lachlan Fold Belt. Much is either National Park, or used for sheep, and to a lesser extent cattle, grazing. The river in its lower reaches is incised into Permian and Triassic sandstones of the Sydney Basin, and is presently dammed (Tallowa Dam) where it is joined by the Kangaroo River, about 20 km upstream from the tidal limit at Berrys Department. There is a major bridge across the river at Nowra, located about 20 km from the coast (Figure 1). East of Nowra there are extensive low-lying alluvial plains, developed as part of the deltaic-estuarine formation of the area, supporting productive pastureland for dairy-farming. Broughton Creek joins the Shoalhaven River at Bolong, itself flowing through low-lying plains for more than 10 km, as far north as Berry.
Figure 1 The alluvial plains flanking the lower Shoalhaven River, New South Wales. Plains morphology is based upon detailed surveying undertaken as part of flood mitigation in the 1970s.
The tidal range at the coast is around 1.6 m. In the past, flash flooding was a feature of the Shoalhaven River, but this has been smoothed as a result of construction of the dam. In the estuarine reaches salinity is substantially reduced by flood waters. The Shoalhaven River intermittently discharges to the sea at Shoalhaven Heads, but since 1822, much of the flow of the Shoalhaven River has exited through Crookhaven Heads. At that time, after convict fatalities as a result of navigating the dangerous shoals at Shoalhaven Heads, a local landowner, Alexander Berry, cut a canal link with the considerably smaller Crookhaven River, diverting the majority of the flow. Berrys Canal continues to widen through bank erosion. After breaching of the sand barrier at Shoalhaven Heads during major flood events, the beach berm is gradually re-established over subsequent months (Healthy Rivers Commission, 1999). Crookhaven River is a much smaller river, with only a very restricted catchment, while Crookhaven Heads, being protected behind the headland, and with training walls provides a permanent opening.

The deltaic-estuarine plains are subject to overbank flooding, and have been drained by a series of drainage dykes. These were substantially upgraded in the 1970s. Drainage of the underlying pyritic sediments has had an impact in terms of fish kills. At present stream bank and gully erosion contribute to the sediment load in the river (Healthy Rivers Commission, 1999).

Methods

The sediments underlying the plains were examined using motorised augers. Many of the augerholes were undertaken using a trailer-mounted Rig-O-Mobile with solid augers to reach 4.5 m depth. Deeper holes were undertaken with a truck-mounted Gemco 210HD rig, with solid augers. Undisturbed cores were examined in a few locations, using a thin-walled sampler lowered through a sequence of hollow augers on the Gemco rig. Sediments were described in the field for texture and colour, and samples were collected for further analysis.

Sediment size characteristics, confirming field observations, were analysed for several samples using a Horiba Capa 700 particle size analyser. Samples were washed through a fine mesh sieve to separate molluscs for later identification. Diatom analysis was undertaken on samples from one augerhole.

The time of deposition was determined for samples of molluscs, and for wood fragments, using radiocarbon dating. Conventional radiocarbon dates were determined both at the Australian National University Radiocarbon Dating Laboratory and Beta Analytic, Florida. In addition, smaller samples were analysed by AMS radiocarbon dating, undertaken at Nagoya University and at the Australian Nuclear Science and Technology Organisation ANTARES accelerator facility. Ages of marine carbonate (shells) have been environmentally-corrected for the marine reservoir effect by the subtraction of 450±35 years, the apparent radiocarbon age of modern carbonates (see Table 1).

Plains Morphology

Figure 1 shows the morphology of the plains. The Shoalhaven River has a sandy bed downstream of Nowra, and braids around several sandy islands (Pig Island, Numbaa Island). Further downstream, it diverts through Berrys Canal and in its lower
course contains a number of muddy, mangrove-covered islands.

The plains are contained within a bedrock embayment. Mount Coolangatta and associated ridge separates the low-lying plains flanking Broughton Creek from the extensive beach-ridge plain of Seven Mile Beach. Bedrock remnants outcrop at Greenwell Point, and the area around Orient Point and Culburra has acted as an anchor, to which are attached the drift-aligned beaches of Comerong Island and Seven Mile Beach. The broad topography of the plains has been determined from Flood Mitigation maps compiled by Kazi in the 1960s. These maps show elevations in feet, but have been metricated and generalised to derive the morphology shown in Figure 1.

The development of levees along the major channels has served to impound a series of flood basins which are prone to inundation during large overbank floods, and which remain wet when the higher areas of the plains have dried out. The area north of the Shoalhaven River is impounded behind a levee formed along the north bank of the river, but in this case overlying older sediments. The nature and age of these sediments have been discussed in detail by Young et al. (1996). Pleistocene sediments outcrop on the river bank, identifiable as highly weathered clayey sands with strong oxidation mottling. At least two stages of deposition have been recognised on the basis of thermoluminescence dating (TL), a lower unit which has been dated >106,000 years old, and a younger unit 15,000-25,000 years old. These are probably remains of alluvial deposits formed when the sea was lower and the Shoalhaven River drained an exposed landscape, draining towards a shoreline further to the east. These Pleistocene deposits have evidently constrained the course of the Shoalhaven River, as well as impounding the lower-lying areas to the north.

South of the Shoalhaven River, there is a well-developed levée which decreases in elevation until about half way to the coast, beyond which it is only intermittently discernible. There are also two minor levée features which run south towards the Crookhaven River. The larger of these flanks a minor watercourse called Crookhaven Creek. This sandy levée bifurcates from the Shoalhaven River just south of Pig Island and then follows a sinuous course, decreasing in elevation towards the Crookhaven River. The smaller flanks the more sinuous Eelwine Creek, running almost due south. Three major floodbasins are impounded by these levée features: Worrigee Swamp just east of Nowra, Brundee Swamp to the southwest of Crookhaven Creek, and Terara Swamp between Crookhaven and Eelwine Creeks. Further low-lying areas are also found to the northwest and southwest of Greenwell Point, where tidal flats merge into dairy pasture recently retrieved from tidal inundation.

Aerial photographs reveal a complex pattern of river meander, point-bar formation and lateral accretion as the Shoalhaven River approaches Shoalhaven Heads. Thus point bars north of Old Man Island, and Old Man Island itself, indicate movement of the river. A series of recurved features identifiable on Comerong Island are also evidence of former meandering courses of the river through this area, at a time prior to the formation of Berrys Canal, when it would appear that the river (or at least a part of its flow) discharged through Crookhaven Heads.
Deltaic-Estuarine Sediments

The stratigraphy of 67 drillholes across the plains is shown in Figure 2. Augerholes were particularly concentrated on the plains themselves rather than on Comerong Island whose origin as a part of the coastal sand-barrier system has been examined by Roy and Thom (Roy, 1984a; Thom et al., 1981; Thom et al., 1978; Roy, 1994). Much of the plains are underlain by mud within which there are abundant, articulate valves of the bivalve mollusc Notospisula trigonella.

The Holocene deltaic-estuarine plains sequence is underlain by Pleistocene sediments. These are generally highly oxidised, reddish, gravelly sands or clay. Over much of the central area the depth at which these are encountered is 4-5 m. In other locations augering was not continued to sufficient depth to encounter these sediments. TL ages of >80,000 (±8,600) years BP on these sediments at 6 m depth in hole SH61 and 67,700 (±5,000) years BP at 20 m depth in SH59, indicate that these sediments were deposited when sea level was lower, during an early part of the last glaciation (Young et al., 1996). Oxidised Pleistocene alluvial sediments such as these, and comparable to those exposed in the riverbank at Bolong, or comprising terrace remnants that form knolls in the Bolong area, were found to underlie the unconsolidated sediments of the plains, and in one drillhole (SH53) bedrock was encountered. These sediments have been a major constraint on the form of the estuarine environments, and their pattern of infill during the Holocene. Much of the area between the Shoalhaven River and Crookhaven River is underlain by Pleistocene sediments at depths of 5 m or shallower.

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Holocene sediments directly overlying this Pleistocene basement tend to be sandier than elsewhere. The Pleistocene surface was evidently flooded as sea level rose and marine waters inundated a previously terrestrial environment, during what is known as the postglacial marine transgression. This marine transgression has been widely described from eastern Australia (Thom and Chappe1, 1975), and a compilation of dates on shells from sand barriers along the coast has enabled definition of an envelope within which sea level changed (Thom and Roy, 1985). The sea was more than 10 m below present 8000 years ago, reaching its present level around 6000-6500 radiocarbon years BP. Radiocarbon dates of 7810 ± 55 years BP on marine shells at 19 m in SH59, and 7190 ± 90 years BP on Notospisula at 9 m in SH98 presumably reflect this initial inundation of the area. However, as will be demonstrated below, sedimentation has not kept up with water level throughout the whole region, and radiocarbon ages reflect the time at which sufficient sediments had accumulated to support the molluscan infauna.

The Holocene sediments comprise both mud and sand. Sandy sediments are encountered in auger holes nearer the coast. The sediments in these holes comprise >90% sand and less than 10% mud, with subrounded to rounded clean quartz, minor rounded black chert and rare feldspar. Calcareous content is typically 35-40%. These sediments occur within about 4 km of the coast. Thus SH80 on Comerong Island penetrated 27 m of sand, though in SH21 muddy sand overlies mud. Sand also characterises SH84, with abundant shell hash and fragments throughout. The lower section of SH34 is also characterised by mollusc-rich sand and a radiocarbon date on
Figure 2 The stratigraphy of the plains flanking the lower Shoalhaven River based upon extensive drilling.
shell \((Austrocochea \text{ and } Bittium)\) of 5990 ± 120 years BP was obtained at 3.5 m depth.

Within flood basins, sediments are entirely mud, ranging from clay to silty clay, with < 5 % sand, and generally 20-30% carbonate. The mud is presumed fluvial in origin, but the molluscan fauna testifies to deposition in a brackish estuarine setting. Similar floodplain clays more recently deposited in overbank flooding, do not contain molluscs and are alluvial in origin. Muddy sand is found associated with Shoalhaven River levées, and with the former levées which flank Eelwine and Crookhaven Creeks.

Angular, subangular or sub-rounded sands, with sedimentary lithic grains (10-15%), iron-stained quartz (5%) and black chert/phyllite grains, and an absence of carbonate are interpreted as river sands.

**Molluscan Composition**

The most obvious macrofossils in drillholes are the molluscs. A detailed compositional study of these has been undertaken by Buman (1995). By far the most abundant mollusc is the bivalve *Notospisula trigonella*. This is found throughout the muddy sediments of the deltaic-estuarine plains.

In drillholes towards the coast the occurrence of species with a marine affinity increases. These are typically species, often gastropods, which tolerate saline conditions (30-35 %), such as *Austrocochea constricta, Katelysia scalarina, Linopyrga pascoei, Tornatina apicina, Pseudoliotia micans, Microcolus dunkeri, Bittium laceritum, Bankivia fasciata* and *Prothallotia comtessei*. This marine suite of molluscs is typical of the more seaward drill holes, up to 6.5 km from the present estuary mouth. It often occurs directly over the pre-Holocene sediments, and forms the lower part of drillholes which may become more estuarine in their upper parts.

Estuarine sediments are dominated by the bivalve *Notospisula trigonella*, often occurring as articulate and apparently in situ, with no other associated molluscs. *Anadara trapezia* and *Pseudoliotia micans* are characteristic of the transition from marine to estuarine conditions within drillholes, and may grade up into monospecific *Notospisula. Tellina deltioides, Nassarius burchardi* and *N. jonasi* are also found in estuarine sediments, often with *Notospisula*. This estuarine assemblage of molluscs is widespread within the sediments of the estuarine plains of the lower Shoalhaven River, characterising all but the seawardmost drillholes. *Notospisula* occurs throughout estuarine environments in NSW; it tolerates a range of salinity conditions, and can be found in various substrates, but is more likely to be dominant in muddy conditions (Jones et al., 1986).

**Diatom Composition**

Molluscs are generally absent from the uppermost part of each core. Indeed, though detailed levelling of each drill site was not undertaken, comparison with the flood mitigation maps, suggests that molluscs are not found above an elevation corresponding to mean sea level, as also noted for a short flood basin to levé transect previously described from near SH63 (Willett and Walker, 1982). The silty clay at the top of the drillholes has presumably been laid down under freshwater conditions. However, in the absence of macrofossil remains, except the cones of the swamp oak, *Casuarina glauca*, found in recently renovated ditches at Jaspers Brush, an
investigation of diatom assemblages was undertaken. The broad pattern found in SH51, near Jaspers Brush, comprised a change from marine-brackish water diatoms within the estuarine sediments to a freshwater assemblage in the surface sediments. The estuarine muds, which contain the bivalve Notospisula, contain marine to brackish diatoms such as Nitzschia cocconeiformis, Cocconeis scutellum, and Coscinodiscus sp. at 100-150 cm depth. The freshwater assemblage is characterised by Nitzschia furstulm, N. palea, N. brevissima, Achnanthes minutissima, and Eunotia spp. More detailed quantitative studies of the diatoms in this and other drillholes is under way (Umitsu et al., in prep.)

Plains Evolution

It is clear that the deltaic-estuarine plains of the lower Shoalhaven River have evolved as a brackish water estuarine environment, subsequently being replaced by freshwater alluvial plains. The transition has occurred as areas became impounded and hence remote from tidal inundation, or as sediments built up beyond the limit of tidal flooding. In fact, survey results indicate that few areas of the plains, except those which have formed as levees, are actually above the elevation reached by high spring tides at the coast. This can be explained partly because the tidal amplitude is presumably reduced as a result of the attenuation of tides through the complex, and evolving, morphology of the plains, and partly because the route by which tidal water gains access to the plains is circuitous, and leads to further frictional dampening of tides.

Our results broadly support the model of Roy, and the preliminary mid-Holocene dates reported by Willett and Walker (4280 ± 110 years BP on sediment and 3800 ± 100 years BP on shells). However, the detailed stratigraphy and chronology provide a more exact interpretation of the sequence of infill of this system. Basal dates in SH 59, SH 98, SH 61 and SH 82 record the transgression as sea water flooded into the embayment formed behind the coastal sand barrier. The continuity of the sand barrier remains difficult to ascertain (Roy, 1994); thus it may have been breached at Shoalhaven Heads and Crookhaven Heads, or conversely it may have been open only at Crookhaven Heads.

When the sea reached its present level, most of the area of the present plains was flooded as part of a large coastal embayment. A coastal lagoon, similar in extent to Lake Illawarra, must have been formed, enclosed partially to seaward by the incipient barrier system. This lagoon received fluvial input from Broughton Creek to the north, and the Shoalhaven River to the west. Exchange with the open sea is recorded by the marine assemblage of molluscs found both north and south of the Greenwell Point rock promontory, and radiocarbon dated at 5990 ± 120 years BP at 3.5 m depth in SH34 (and 5360 ± 80 years BP at 0.9 m in the same hole), 6510 ± 120 years BP at 5.4 m in SH87, 5820 ± 110 years BP at 5.4 m in SH93, and 6090 ± 60 years BP (Beta 84640 reported in Young et al. 1996) on molluscs in association with fluvial sand adjacent to the northern part of Berrys Canal.

Estuarine sedimentation within the major part of the plains lagged behind marine sedimentation around Greenwell Point, as the lagoon was infilled with sediment within which Notospisula was prominent. The gradual accretion is reflected by the sequence of dates on shells within SH98 (7190 ± 90 years BP at 9 m depth, 4620 ± 80 years BP at 4.5 m, and 4580 ± 80 years BP
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through Crookhaven Heads. Under this interpretation, the present west-east course of the Shoalhaven River is considered to be a more recently adopted diversion, presumably resulting from breaching at Shoalhaven Heads during a major flood event. By contrast, Young et al. (1996) identify fluvioglacial basins and within molluscs dated 6090 years BP near Berrys Canal, on the basis of which they infer that the Shoalhaven River maintained its present course via Shoalhaven Heads, even before the estuarine basin had entirely infilled. They interpret Crookhaven Creek and Eelwine Creek as crevasses splay associated with levee breaches, indicating that their channel dimensions and meander wavelengths are insufficient to accommodate the flow of the Shoalhaven River.

Our drilling and dating results support the age determinations of around 6000 years BP for sediments adjacent to Berrys Canal (5820 years BP in SH93 and 6510 years BP in SH87), but do not indicate lateral continuity of the present levee system at that time. Indeed several ages determined from cores beneath the levee on the southern bank of the Shoalhaven River indicate that this levee is Late Holocene in age (2550 years BP in SH90, 3530 years BP in SH89 and 2340 years BP in SH88). On the other hand, the only age that we could determine on levee or deltaic channel deposits associated with Crookhaven Creek (6740 years BP in SH82) implies that that is the older feature. Sediments throughout drillhole SH60, exceeding 22 m in depth, appear to have been deposited rapidly 5800-5500 years ago. These dates together with the north-south alignment of Eelwine Creek with Broughton Creek to the north appear to lend support to the former interpretation, that proposed by Roy. However, as lateral migration of the Shoalhaven River may have

at 2.0 m) and SH85 (6410 ± 85 years BP at 6.8 m, 5690 ± 60 years BP at 3.5 m, and 5420 ± 105 years BP at 2.5 m).

The pattern appears to be one of sedimentation around the periphery and gradual infill in the centre of the flood basins. Thus a basal date of 5710 ± 90 years BP records initiation of sedimentation in SH35, but a near-surface date of 3070 ± 100 near the upper occurrence of molluscs in SH26 implies that much of the Brundee Swamp basin had been infilled under estuarine conditions by 3000 years BP. Much of the plains flanking Broughton Creek infilled between 5000 and 4000 years BP, and much of the plains south of the river filled in 5500-3500 years BP. The upper occurrence of shells dates around 3500 years BP in SH7, SH24, SH30, SH63 and SH89. Tidal conditions still persist through the Crookhaven system, as indicated by the name Saltwater Swamp. Sedimentation appears to have begun here later, with a basal date of 2500 years BP in SH38. Similar young ages have been found in drillholes SH88 and SH90 and indicate persistence of estuarine conditions at these sites.

It is evident that the course occupied by the channel of the Shoalhaven River has migrated across the plains during the 6000 years that it has taken for the estuarine system to infill. In the model proposed by Roy (1994), the Shoalhaven River and Broughton Creek are shown schematically emptying into the large barrier-estuary lagoon, and gradually building across that lagoon by extension of a bay-head fluvial delta. Crookhaven Creek is inferred to represent an old course of the Shoalhaven River, and Eelwine Creek an old course of Broughton Creek (from which it runs directly southward), both presumably exiting
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References


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of coastal sand barriers in New South Wales, Australia. Geography Department, Faculty of Military Studies, University of NSW, Dunrobin, Canberra, 86 pp.


Table 1 Radiocarbon dating results from the Lower Shoalhaven River plains

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* ANU, Australian National University; Beta, Beta Analytic; NUTA Nagoya University Tandem Accelerator; OZD, ANSTO, ANTARES Australian Nuclear Science and Technology Organisation (AINSE grant 98/123).